

Animal production and the future use of cottonseed.

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Abstract

Cotton is one of the few crops with a positive carbon foot print being a source of fiber, oil (fuel), protein meal and forage as hull.

The seed contains gossypol which is toxic to monogastric animals at moderate levels of inclusion in their diets but does not affect ruminants at the dietary inclusion rates recommended. The whole or fuzzy white cottonseed and the hulls are excellent drought feeds for cattle and sheep and sources of effective fiber in the diets of high yielding dairy cows, particularly those that are in the urban areas of China, Korea and Japan that suffer rumen acidosis from dietary grain over load.

The major role for cottonseed by-products resides with the by-product meal which is an excellent source of bypass protein that is required when animals are consuming mature forages, such as dried off pasture biomass and cereal crop residues.

Future world meat and milk production has to increase to feed a population of 8-10 billion people within a few years. Feed resources to increase animal production will be limited by decreasing availability of cereal grains in the future as climate change, resource depletion and competition with food and fuel uses, limit grain availability. The only likely available feed biomass that is underutilized are crop by-products and residues. The only feasible future approach to increase animal protein availability will be to use herbivores and ruminants in particular fed straws and improve their efficiency of utilisation of such materials. Bypass proteins will be critical as technology develops to use particularly the 3 billion tonnes of straw produced annually throughout the world. Harnessing the (cottonseed meal) CSM produced in Australia for efficient ruminant production is an urgent priority as it stimulates all production parameters and the efficiency of use of these low digestibility forages by ruminants.

Introduction

Cotton fields represent approximately 2.5% of the world's agricultural land, and produce 36% of the world's textiles, the remaining coming from fossil fuels (synthetics) 54%, wool 2% and rayon and others 5%.

Cotton is more than just a fiber source. Cottonseed, a valuable byproduct of fiber production is used in numerous food and industrial applications. For every kg of fiber produced, 1.5-1.7kg of cottonseed is

also produced. One ton of seed, yields about 200 kg of oil, 500 kg of cottonseed meal (CSM) and 300 kg of hulls. All of which have value in the animal feed industry.

The average amount of energy required to produce cotton from planting through to the ginning process has been estimated to be 20 GJ per tonne; the embedded energy in the seed alone is estimated to be 32.5 GJ, even with 60% energy conversion efficiency, the energy in the seed has been calculated to equal the amount of energy needed to produce the crop (Barners and Reed 2009). The carbon foot print of cotton therefore depends on the efficient use of the seed components for fuel, feed for animals and to a lesser extent food for humans. Using the energy and protein of the seed efficiently is a priority in a resource limited world with an ever increasing problem of global warming.

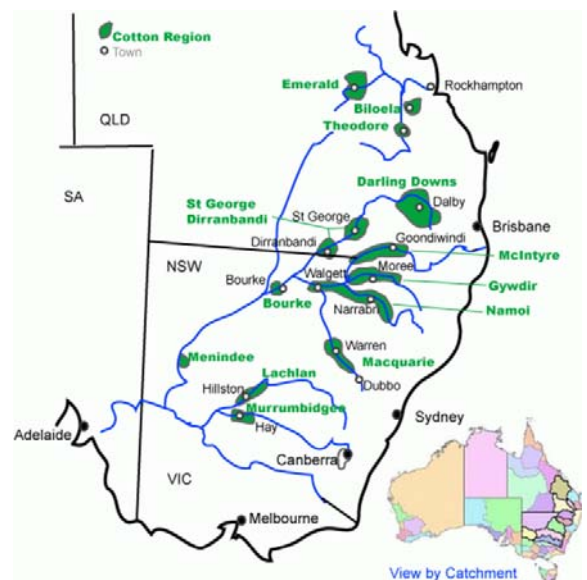
The production of cotton is strategically distributed adjacent to the major areas of cattle and sheep grazing country in NSW and Queensland, which is subjected to annual droughts when feed dries off from lack of moisture or cold conditions and where cottonseed plays important roles as a potential drought feed (fuzzy cottonseed and hulls) or as a critical and catalytic supplement (cottonseed meal or CSM) to poor quality roughages (Leng 1990).

Cotton byproducts in animal nutrition

Gossypol limits the animal species that can be fed with cottonseed and its by-products

The seed embryo contains a large number of vacuoles filled with a yellow pigment- gossypol. Gossypol is a polyphenolic aldehyde which is an antioxidant and is toxic to monogastric animals at relatively low intakes. Pigs and rabbits are the most sensitive and poultry are more tolerant. Although acute toxicity is low, intake over a prolonged period may be fatal. It is important to distinguish between free and bound gossypol since only the former is considered to be physiologically active.

Free gossypol content of cottonseed meal declines during processing but this varies according to the methods used. In new seed, free gossypol accounts for 0.4-1.4% of the weight of the kernel. Screw pressed materials have 200-500 mg free gossypol/kg, pre pressed solvent extracted meals 200-700 and solvent extracted 1000-5000 mg/kg. Processing conditions have to be carefully controlled to prevent loss of protein quality owing to binding of gossypol to lysine at high temperatures. The inclusions of cottonseed meal should be between 50-100 kg/t of feed for pig and poultry and particular care is required with poultry since low levels of the meal may cause a green discoloration of the yolk in storage.



Cottonseed, because of the presence of gossypol is only likely to be used extensively in the ruminant feeding industries in the future. Gossypol has been associated with male contraception but with bulls

fed relatively high levels of cottonseed meal there has been no reported reproductive problems; on the contrary testicular degeneration has been prevented or testicular size in bulls has been increased by feeding CSM in far North Queensland studies in dry seasons (see Leng 2003) and at the inclusion rate which exhibits the maximum efficient level of feeding to ruminants on forage based diets the gossypol levels do not become a problem (see below)

Genetically modified cotton

Genetically modified, insect resistant cotton varieties were introduced into Australia cotton industry in 1996 and now represent 90% of cotton grown across the country. There has been no effect on the nutritional value of the by-product's because of these developments. The presence of gossypol in CSM limits its market for inclusion in human and pig and poultry diets. Global cottonseed production can potentially provide the protein requirements for half a billion people per year and many billions of other animals. Elimination of gossypol from cottonseed has been a long-standing goal of geneticists. "Glandless cotton" produced in the 1950s by conventional breeding techniques were commercially unviable because of the increased susceptibility of the plant to insect pests. Recently a group in the USA ([Sunilkumar et al 2006](#)) have demonstrated that it is possible to significantly reduce cottonseed-gossypol levels in a stable and heritable manner. Most relevant to animal nutrition is that the levels of gossypol and related terpenoids in the foliage and floral parts were not diminished, and thus their insects and diseases resistance remained unaffected. Seed gossypol was reduced by as much as 99%. These results provide a mechanism to open up a new source of nutrition for monogastric animals including millions of people in developing countries where cotton remains a cash crop in subsistence farming. However it remains important from the Australian view point to maintain cottonseed meal in its capacity as a very effective feed supplement to the cattle and sheep industries.

A cautionary note on introduction of low gossypol cottonseed

There is a major possibility that gossypol contributes to the change in solubility of the seed protein that accompanies the extraction of edible oils. If this were the case CSM from such genetic mutants would need extra treatment if it is to have the same beneficial effects as the CSM from the present varieties and may introduce a need for further treatment of the meal to ensure its catalytic effects in stimulating cattle and sheep production from mature forages (discussed below).

Cottonseed and ruminant nutrition

Nutritional requirement of ruminants

To facilitate understanding of the arguments for prioritizing cottonseed for ruminant feed some in-depth knowledge of the digestive physiology of ruminants is required. A short summary is given here and more information can be found in Leng (2003) and advanced treatment in Preston and Leng (1986).

The nutritional requirements of cattle, sheep and goats reflect the requirements of the microbes that occupy their rumens. These microbes breakdown feed into volatile fatty acids which are used by the animal as energy, the microbes that produce them gain energy for cell growth. Microbial cells moving in

digesta to the lower tract are a major source of digestible protein and therefore essential amino acids for the animal. Good livestock production relies on a healthy and stable population of rumen microbes, but under many feeding conditions microbial growth rate, even when optimized by supplements of deficient nutrients, such as minerals and urea, does not provide all the amino acids required for optimal production and efficient immune system and therefore health. An additional source of dietary protein that reaches the small intestine before digestion is required for maximum production from the available biomass to grazing ruminants. The amount of extra dietary protein to optimize production from most common feeds depends on the quality of the basal feed resource; productive state and the health of the animal (see Leng 2005)

Whole or fuzzy cottonseed provides a readily rumen digestible protein (RDP) supplying the digesting microbial consortia in the rumen with ammonia, peptides and amino acids for protein synthesis and growth. However, in the process of oil extraction either by pressure or solvent, the protein is altered in its physical structures, making it relatively insoluble and more resistant to microbial digestion. The process of digestion of this protein in the rumen is slowed and allows a high proportion of the CSM protein to move to, and be digested in the intestines, providing a source of protein (termed from now on as bypass protein or BP) to the intestinal tract where it is digested and absorbed augmenting the supply of amino acids from rumen microbes also digested in the same site.

Australian research, in particular, has built a large body of information that shows that CSM supplementation has great implications for the economic production of cattle and sheep under grazing conditions (this is reviewed by Leng, 2003; Poppi and McClennan 1995).

Efficient utilization of the available feed resources by ruminant animals depends on two rules of thumb.

1. Optimization of the nutrition of the microbial consortia that ferment the feed within the rumen by ensuring no deficiencies of microbial nutrients (ammonia which is usually supplied as RDP or urea and minerals –termed rumen nutrients from now on) and adequate habitat for microbial growth (this is accepted by a high percentage of livestock producers)
2. Providing a source of extra protein for post ruminal digestion to meet the extra demand for protein in growing, lactating or pregnant animals and to meet the higher demands for essential amino acids by the immune system in diseased animals (particularly intestinal parasites) (applied by very few producers). CSM an ideal source of bypass protein

Supplementation strategies for young cattle on low quality forage

A number of researchers around the world have shown the enormous benefits of supplementary bypass protein to both cattle and sheep fed forage, particularly where the forage is mature. Typical data from these studies are shown in Figure 1. In order to remove some of the variability of weight of animals used in different experiments and the differences of quality of protein meals, the intake of supplement is expressed in, g crude protein intake per kg body weight per day (gCP/kg LWt/d) and the response is calculated as the increase in live weight gain (kg/d) over that of animals with no bypass protein in the diet but fed adequate amounts of rumen nutrients (from Leng, 2004). The relationship of bypass protein intake and growth response in cattle on mature forage is described most accurately by a log linear

relationship indicating a diminishing response to increasing intake of crude protein (see Figure 1). For practical application the response may be divided into an initial steep linear response followed by a much lower response at higher intakes of CSM supplement (Figure 2).These two response relationships may be attributed to:

- An initial effect of an increased MP supply and a more balanced array of nutrients for efficient live weight gain (for instance the response in a 200kg steer is 1.2 g gain / 1g cottonseed meal (42% CP) consumed). Total feed intake was either unaffected or slightly increased over this initial supplement range (0-1g CP/kg LWt /day) and therefore the improved growth was mainly attributable to increased feed conversion efficiency.
- At intakes above 1gCP/kg LWt/day there was a lower response per unit of supplement (0.32 g gain per 1g cottonseed meal consumed). The total feed intake was increased but at the higher rates of supplementation a substitution effect was apparent. The overall greater availability of nutrients following the initial improved feed conversion efficiency (an effect compatible with increased ME intake) can explain the increased live weight gain with supplement levels above 1g CP/kg LWt/day.

To summarise where cattle are fed mature forages over an initial supplement from 0 to 500g/head per day of CSM, young cattle gain approximately 1g weight gain per g of extra CSM fed. Provided growth rates without supplements are known this allows graziers to match their supplementation strategies with production targets. Similar production responses have been recorded for sheep with additional increased wool growth.

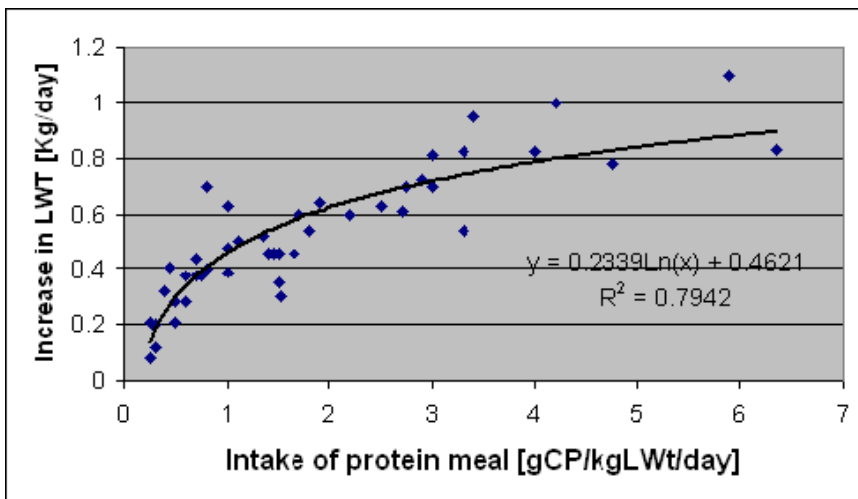


Figure 1. The effects of increasing the intake of bypass protein in young cattle consuming a 'poor quality forage' that is adequately supplemented with N (to meet rumen ammonia requirements) and minerals (Leng, 2004).

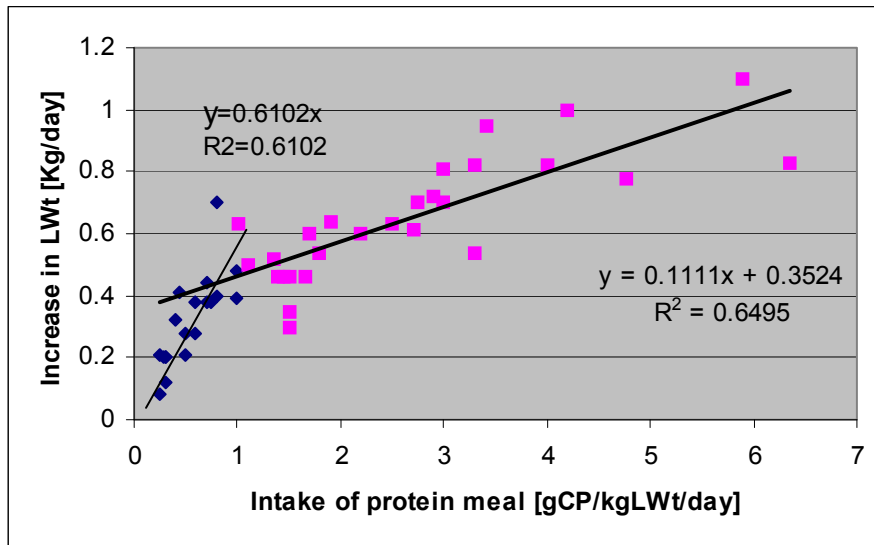


Figure 2. The potential to describe the results as two distinct sets of data described by independent linear regressions. These regressions are intended to provide prediction equations relatively easily understood(Leng 2004).

Other situations where a bypass protein has major effects on productivity of ruminants.

The response of young ruminants fed on mature forages to supplementation with CSM as shown above is also manifest in similar situations in improving reproductive efficiency and survival, increasing milk yield and supporting a better immune system thus reducing the effects of, in particular, of intestinal parasites and indirectly reducing the development of resistance of intestinal parasites to anthelmintics, an increasing problem in the grazing industries. Time or space only allows for discussions on the benefits of correct supplementation of mature forages has on growth rate here (see below) As it will be argued below CSM is a catalytic supplement essential in future animal protein production and as such the industry should take steps to value add to this by product. In feeding situations where feed quality is poor applying the two rules of thumb referred to above most production indices in cattle and sheep are improved substantially, including reproductive efficiency ,pregnancy rates, milk production and survival of new born animals and subsequent growth rates together with resistance to ill thrift from parasitise infection. This is fully discussed in the book by Leng (2003.)

As a mineral/ phosphorus (P) source for cattle and sheep feeding on low quality forages.

In much of Australia grazing areas, soil P is relatively unavailable being fixed in a clay matrix, as a result cattle and sheep experience P deficiency in the forage they consume. P deficiency is greatest in the mature dried off pasture and also in cereal crop residues but the symptoms of P deficiency are more apparent in tropical pastures during the green season when other nutrients are non-limiting and P requirements are enhanced (McCosker and Winks 1994). The major effects of P deficiency in grazing ruminants are low feed intake and low reproductive efficiency. It is not uncommon in northern grazing situations without P supplementation, cattle will calve once every second year. A strategy for feeding by pass protein with multi-mineral urea sources to grazing ruminants or those fed crop residues ,corrects a

number of mineral deficiencies including P deficiency and lifts calving percentages towards the desirable once a year scenario. P fertilizers are in high demand worldwide and the high grade ores from which they are manufactured are being depleted with suggestions that the world has arrived at Peak P (Bardi and Pagani 2007) and P fertilizers are likely to become scarce and costly in the future.

Why are cereal crop residues and bypass proteins such as CSM so important for future animal feed?

The food requirements and animal protein resources to meet a projected human population of 8 billion people in the decade 2030-2040 appear to be unattainable when it is considered that the world is faced with a triple crisis: climate change, peak oil (the end of inexpensive energy) and global resource depletion. The certainties are that there will be great changes to contend with in the future in order to produce and deliver food to maintain the present world population. The age of scarce, readily extractable fossil energy and therefore high fuel costs has arrived. Even though large quantities of oil and gas are available deep in the earth's crust and technology is available for tapping these resources (e.g. fracking) these are unlikely to reduce the cost of energy in real terms for logistic reasons. The high and likely increasing cost of energy heralds large changes in the financial and related political structures. Without rationalization of the use of fossil energy there seems to be little chance of continuing world growth. Inexpensive oil allowed food to be produced cheaply but this will change greatly as fossil fuel prices rise creating the potential for major disruptions in food and animal feed availability.

Agriculture has received inexpensive chemicals and fertilizers on which high crop yields have been predicated, including: nitrogenous fertilizers manufactured from natural gas, mined phosphate reserves which have peaked (Bardi and Pagani 2007; Déry P and Anderson B 2007). The world is now dependent on extracting phosphate fertilizers from low grade rock phosphate at high energy costs. Irrigation waters from aquifers and rivers have also been depleted in some of the major cereal producing areas. The advent of the high cost of fuel and therefore power for irrigation will clearly cause a return of vast areas of highly productive crop land back to rain fed cropping, pasture or desert with major loss of food productivity. Soil erosion and fertilizer run off from cropping systems are also major concerns as tillage and crop management have eroded top soil of large areas of land that will inevitably lead to decreased crop yields.

The dependency of the industrialized countries on imported oil has seen a headlong development of bio-fuel from sugar cane and maize mainly in Brazil and the USA respectively and bio diesel from plant oils, creating major cereal food /feed grain shortages. The expectation is that world cereal grain availability for livestock feed will be highly restricted, with major decline in factory farming of livestock. Herbivores are likely to be used more extensively with time, particularly the ruminant.

It appears that the world now enters a time where grain based animal production will become increasingly expensive as competition for food, feed and biofuel develops. The animal production industries based on herbivores will need extensive development, exploiting a wide range of waste by-products of agriculture or biomass from land not dedicated to food or biofuel production.

The huge amounts of by-product feed from industrial alcohol production from grain, provides a source of nutrients for all animal industries. It appears that these can be included in the typical beef feed lot diets, up to 30% and some will find its way into the pig and poultry diets (see Babcock et al., 2008). It is estimated that annual DDGS production in the United States is about 40 million metric tons (Tokgoz et al., 2007). However the high costs of drying and or transport of wet material are serious limitations to their use, except in the vicinity of distilleries. Residues of antibiotics in the byproduct may also be a future constraint as many countries are now banning the use of antibiotics in animal production. The great asset of CSM as a bypass protein source is its application close to the farming systems that use it as a catalytic supplement.

Ruminants fed forages offer the most reliable source of meat in the future

Forty per cent of the earth's land surface supports the majority of the world's 3.3 billion cattle, sheep, and goats. Most of these pastoral areas cannot be economically cropped; half are moderately degraded; 5 per cent are severely degraded, particularly the communal lands. Forage requirements of the large livestock population in nearly all countries appear to exceed the sustainable yield of rangelands and other forage resources such as agro industrial by-products (Brown, 2009).

Future increases in animal protein production must depend heavily on crop by-products

The world produces just fewer than 2 billion tonnes of cereal grains which is accompanied by about the same yield as straw or stover. Straw has a number of uses; it is fed to ruminants, mostly without appreciation of production responses that could be achieved with treatment and supplementation; it may be burned to facilitate multiple cropping practices and it is, in places, harvested for other commercial purposes or ploughed back into the land.

Crop residues can support surprisingly high levels of ruminant production

Crop residues particularly straw can support moderate-high levels of production in ruminants provided efficient means of treating the straw to enhance digestibility and any deficiencies of nutrients in a diet are corrected. If additional bypass protein is then provided, levels of production and efficiency of use of biomass for growth and milk production are greatly improved (see Leng, 1991; 2004). The improvements in utilisation of straw by ruminants by adhering to these simple principles are now well demonstrated. In India milk production, largely from cows fed straw has escalated by the application of good nutritional principles among other applications (see Banarjee, 1994). In northern wheat belt of China cattle growth rates on straw, with enhanced digestibility and supplemented with CSM approached 0.9kg per day or 75% of the rate that could be achieved with similar animals fed grain based feed lot diets (see Cungen et al., 1999). At these growth rates the numbers of animals that can be fattened on the same quantity of untreated straw increases 10-13 fold (see Table 1).

The vast majority ruminants, which number some 1800 million large ruminant equivalents, are low producing and can be upgraded to moderate to high levels of production with modern technology. There are 2 billion tonnes of straw that could be converted into animal products with a feed conversion efficiencies of about 10:1 This could produce 200 million tonnes of live animal annually which could

support 4 billion people at 25 kg/year. Thus with information transfer and political will ruminant production systems could be the major development for production of animal protein in the future. CSM is a critical nutrient that can supply the needs of the ruminant industries if used close to the site of production and requires no processing other than pelleting to facilitate transport and feeding out (see adjacent figure) .

Table 1. The potential of balanced supplementation to increase meat production from young cattle fed low quality crop residues treated to increase digestibility. The calculations are based on the data from research in Hebei, China as reported by Dolberg & Finlayson (1995).

Cottonseed supplement fed[kg/day]	0	0.25	0.5	1.5	2.0	2.5
Live weight gain[g/day]	63	370	529	781	829	892
Straw consumed to produce 100kg live weight [tonnes]	6	1.1	0.92	0.56	0.48	0.46
Cottonseed cake consumed [tonnes] to produce 100kg live weight	0	.1	.1	.14	.22	.24
Number of animals that can achieve an extra 100kg of live weight on 6 tonnes of straw	1	5+	6+	10+	12+	13+
Protein meal requirements [tones] to allow 100g live weight gain per group of animals fattened	0	.5	.6	1.4	2.6	3.1
Conversion of protein meal to live weight [g Lwt gain/g feed concentrate]	-	1.2:1	.93:1	.48:1	.26:1	.31:1

The downside of ruminant production from mature roughages

Slow growth, low milk yield and poor reproductive performance result in poor feed conversion and a large methane output relative to product output. (see Leng, 1991).The benefits of high growth rates as a means of reducing methane production per unit of meat production have been confirmed from direct measures of methane output (Figure 3) Provided growth rates (in cattle) are between 0.7 and 1 kg/day, methane production will be minimised and these upper levels of growth are being achieved with cattle fed crop residues (see for example Dolberg and Finlayson, 1995). In addition at these growth rates it is possible to produce quality meat for all the major markets of the world. Thus an answer to world meat shortages, when industrialised production systems become too expensive, is to develop ruminant production systems from crop by-products in industrialised countries and ensure a large input into research and extension in the developing countries to achieve the levels of production at minimal cost to the environment and without increasing livestock numbers

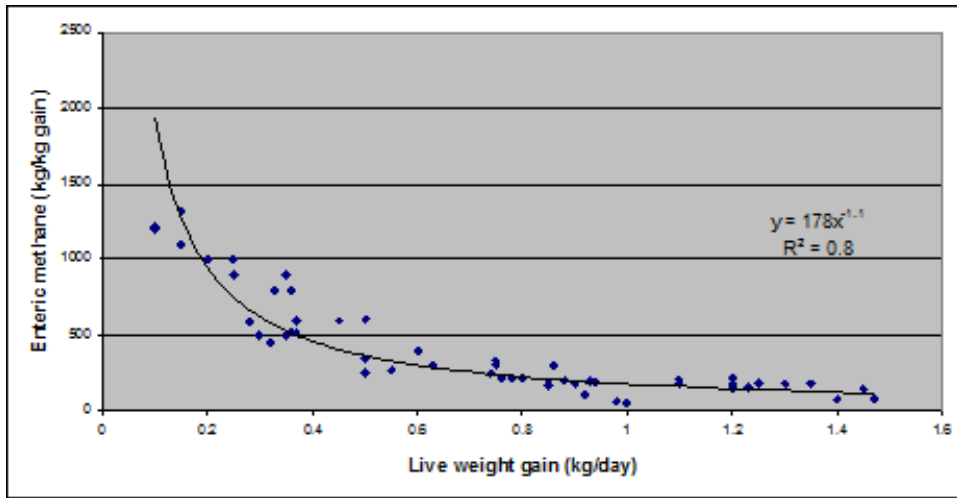


Figure 3. The relationship between live weight gain of cattle and enteric methane production per kg of gain (see Klieve and Ouwerkerk (2007) for sources)

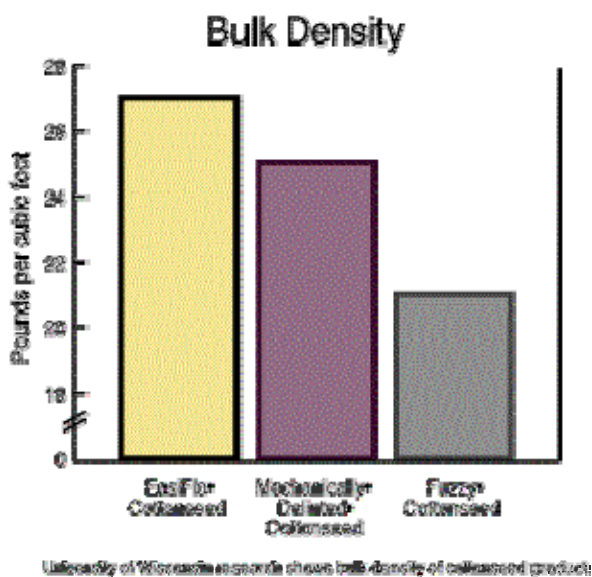
Potential of fuzzy cottonseed in animal production

Drought feeding

The priority use of cottonseed will be for CSM with the production of by product oil that can be used in the feed industry or as renewable fuel. However white whole cottonseed has a role in drought feeding when other feeds are scarce. It can be fed as a drought feed without supplementation or a production feed with supplementation of a bypass protein e.g. CSM. It can also be combined with the hulls in drought feeding rations(see Leng 2003)

Effective fiber for high yielding dairy cows.

Whole cottonseed has enormous value as effective fiber in dairy cow diets based on high intakes of grain based concentrates (Zebali et al 2012). In many of the large cities of Asia and the oil rich states of the Middle East dairy production has developed within the city boundaries, particularly in port cities where imported concentrates arrive in the country. The increasing urbanisation and increased wealth of our Asian neighbours has created a demand for milk and in the dense urban areas the systems that have evolved follow the developed country models of milk production based on high yielding dairy cows fed excessive amounts of grains. In these diets the roughage component of the diet is critical for prevention of rumen health disorders and because of the siting of dairies it is the most costly component of the diet. To avoid rumen health problems and their



University of Wisconsin-Madison Extension shows bulk density of cottonseed products

related losses of production these dairies need to feed an effective fiber. Cottonseed falls into this category. As dairy cow enterprises, with acute problems are willing to pay high prices for effective fiber there is a large and growing trade in forages for importation even from far away countries. Fuzzy cottonseed is also regarded as an excellent source of fibre. Its major problem is that of packaging because of its low bulk density but this has been overcome by coating fuzzy cotton seed with starch. As a result, up to 25 percent more cottonseed may be stored in the same amount of space originally used for whole cottonseed. This density advantage also lowers shipping costs.

Cottonseed hull as a potential high quality source of effective fiber but requires some form of densification to enable it to enter an export market competitively. Cottonseed hulls are the parts of the cottonseed head that is left after the cotton and meal have been extracted and are normally considered to be a very low quality feed for ruminants. The results of two trials have shown that they are capable of supporting moderate growth rates in sheep. When a small amount of by-pass protein was added to the diet of cottonseed hulls + urea + 50 g lucerne + vitamins/minerals, the growth rate of lambs exceeded 130 g/day (Davis and Leng 1989) and wool growth was increased from 6 to 9 g/day.

Intake of cottonseed hulls by sheep is higher (c. 1 kg DM/day) than would be expected of a 40% digestible feed and this is possibly associated with a rapid breakdown of the indigestible material in the rumen.

Conclusions

Cotton will continue to be a preferred fiber and is likely to be more competitive with synthetic fibres in the future because of the increasing cost of fossil fuels from which they are produced. However the cotton industry should be doing more to promote the value of cotton's by-products which have major roles in future meat and milk production. The attributes of CSM as a by-pass protein in feeding ruminants particularly when only mature forages are available has not been given the emphasis by the industry it deserves. Although CSM production in Australia is relatively small on a world basis, it is produced at sites which are close to where the by-products are used e.g. grazing land and cereal crop farming where transport costs are a less significant proportion of the overall costs

The benefits of feeding cottonseed by-products although emphasised in the scientific literature are less appreciated in the industry and have an enormous capacity to increase livestock productivity at times when feed resources are mature and or based on cereal crop residues. The industry should be advertising the by-products in these roles. Australia's cottonseed meal yield, like cotton is weather dependent but an average 350,000 metric tonnes of cotton could easily meet the needs of 60 million sheep and 20 million cattle if successfully marketed.

Future increases in animal protein supplies to support a healthy human population are likely to be based on ruminants that do not compete with monogastric animals for increasingly scarce food (grain) resources. The only large biomass that is available for producing the likely high demand for ruminant products as the population increases towards the 8-10 billion people is crop residues which are massively underutilised or not used at all at present. Mobilising crop residues by treatment to increase digestibility and providing a source of nutrients deficient in the straw to optimise production can have a

highly significant impact on meat, milk and wool production in Australia. At the present time the technology for treatment has not been developed sufficiently and a requirement for successful ruminant production from straw will be diversified local treatment sites. An integrated plan to utilise cereal crop residues requires local utilisation. Cottonseed meal which has already value added to cotton production through the contribution of oil is also fortunately produce adjacent to those areas and is competitive with other potential protein sources which generally need further processing to confer rumen protection.

Adding value to cottonseed hulls and fuzzy cottonseed by processing and decreasing bulk volume could open market access to the demand for effective fiber in the urban dairy industries of China, Japan, Korea and Middle Eastern countries but these may be short term in view of the potential future high cost of feed grains in an ever increasing demand for grain for food, feed and bio fuel which could make urban milk production uneconomic..

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